

THE "OLIGOTROPHICATION" OF LITTLE OTTER LAKE PARRY SOUND DISTRICT

1971 - 1972



Ministry
of the
Environment

Ontario

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THE "OLIGOTROPHICATION" OF

LITTLE OTTER LAKE,

PARRY SOUND DISTRICT -

1971-1972

by

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SUMMARY AND CONCLUSIONS

Little Otter Lake, a small lake in the Precambrian Shield, south of Parry Sound, Ontario (area = 66.5 hectares; volume = $1.85 \times 10^6 \text{ m}^3$), was subjected to an industrial waste discharge during July and August of 1971 which contained high concentrations of a polyphosphate de-scaling agent. Approximately 265 kg of phosphorus was discharged to the lake resulting in a loading of $0.436 \text{ g P m}^{-2} \text{ year}^{-1}$.

In 1971 the lake developed classical symptoms of accelerating eutrophy, including a dense algal bloom dominated by Anabaena limnetica G.M. Smith (19,338 areal standard units ml^{-1}), reduced Secchi disc transparencies (0.1 - 2.3m) and high concentrations of chlorophyll a ($12-46 \mu\text{g l}^{-1}$) and total phosphorus ($12-110 \mu\text{g l}^{-1}$).

The situation was somewhat unique because the only significant input was phosphorus and the lake was essentially a closed system during the summer. In August of 1971, the polyphosphate discharges were discontinued, reducing the loading to $0.036 \text{ g P m}^{-2} \text{ year}^{-1}$. Concomitant improvements in water quality in 1972 included a reduction in phytoplankton densities to levels typical of oligotrophic Precambrian Shield Lakes, increases in Secchi disc transparencies (1.8-5.2m) and decreases in total phosphorus and chlorophyll a concentrations (6-31 and $0.7-4.3 \mu\text{g l}^{-1}$, respectively). Other key nutritional values were essentially the same in 1970 through 1972.

Notwithstanding that the oligotrophication of Little Otter Lake was not exactly typical of a lake being continuously affected by domestic, industrial and/or agricultural wastes, the results of this "lake-scale phosphorus removal study" are most encouraging in light of the Ministry's recently implemented phosphorus removal programme.

INTRODUCTION

In the fall of 1971, personnel of the Biology Section of the Ministry of the Environment were advised of an extensive algal bloom on Little Otter Lake in the District of Parry Sound, (Figure 1).¹ When most severe, the bloom extended throughout the lake, upstream into a small portion of Otter Lake and downstream through Oastler Lake. It was subsequently determined that an industrial waste effluent, which periodically contained high concentrations of a polyphosphate de-scaling agent, was discharged during the months of July and August of 1971 into Little Otter Lake. Use of the de-scaler was discontinued in the fall of 1971; however, as an added safeguard against re-occurrence of the bloom, a proposal was presented during the winter of 1972 by local cottagers and permanent shoreline residents to apply a coagulant-precipitant aid to the lake to ensure that phosphorus levels would not reach concentrations conducive to the development of troublesome levels of algae. Biologists of the Ministry pointed out that remedial action in this direction was somewhat premature. For example, only limited data on both short and long-term effects and frequency of treatment with alum and other precipitants were available, and in particular evidence which clearly documented the impact of treatment on benthic production, zooplankton populations and/or periphytic conditions as well as relationships to phytoplankton stocks was not available. Based on the experience of Edmondson (1971), Schindler et al. (1971), Michalski et al. (1973) and others (Anon. 1969), it was felt that because of the reduction of the phosphorus input to the lake already effected (accomplished in the fall of 1971), nuisance algal blooms would not materialize during the summer of 1972. Additionally, "under-ice" phosphorus levels in March 1972 ranged between 10 and 13 $\mu\text{g l}^{-1}$ (as total phosphorus), suggesting that treatments to inactivate euphotic zone phosphorus would be unnecessary and inconsequential. However, it was recognized that strong public reaction might develop at Little Otter Lake should future water-blooms materialize. As a consequence, a "treat-if-necessary" alternative involving a weekly monitoring programme was established based on collection of information on a number of key parameters so that chemical treatment might be prescribed should troublesome algal levels materialize.

¹ Over the last ten years, Little Otter Lake has received considerable attention with respect to the effects of industrial waste discharges on water quality. As historical background, a summary of pertinent investigations is provided in Appendix A.

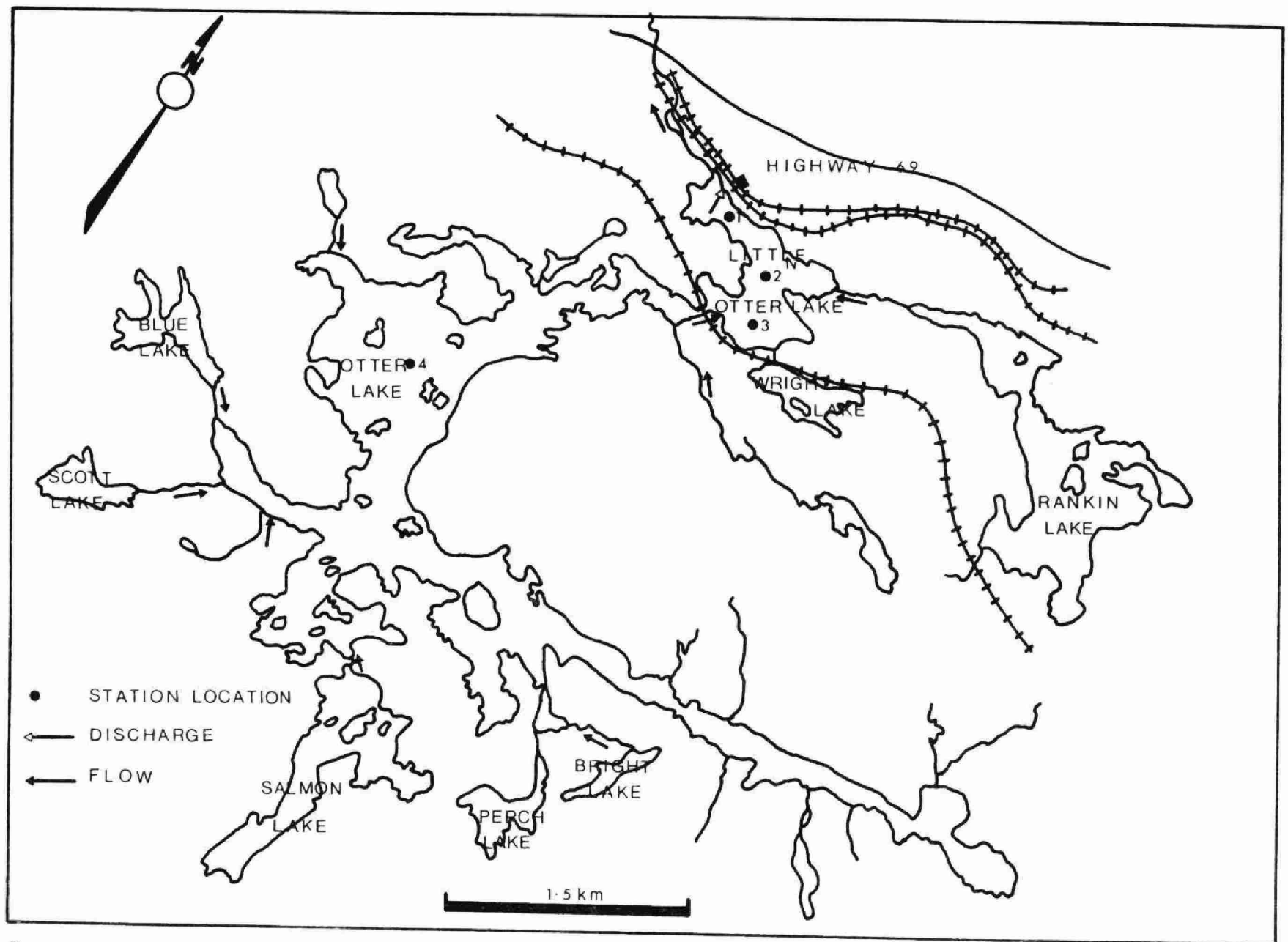


Figure 1: Diagrammatic representation of the Otter-Little Otter Lake watershed. Main lake sampling stations, direction of flows, as well as the Rockwell International discharge point are illustrated.

Subsequently, an excellent opportunity was afforded to evaluate the role of phosphorus in its singular capacity to promote detrimental algal blooms. This report presents a comparison of conditions in Little Otter Lake during and after the period of polyphosphate discharge and comments on the results in context of implications to water quality management in Ontario and in particular, to Ontario's commitment to remove phosphorus from domestic sewage effluents.

DESCRIPTION OF THE STUDY AREA

Little Otter Lake is a small lake in the Precambrian Shield in the Township of Foley, District of Parry Sound, Ontario (45° 20' N - 79° 55' W). The lake occupies an area of 66.5 hectares with a maximum depth of 8 meters and a volume of $1.85 \times 10^6 \text{ m}^3$. It is separated by a small narrows from upstream Otter Lake, a larger, deeper oligotrophic lake. The estimated annual average daily flow from Otter to Little Otter Lake is $35.2 \times 10^3 \text{ m}^3 \text{ day}^{-1}$. Small tributaries and land drainage contribute an additional $11.3 \times 10^3 \text{ m}^3 \text{ day}^{-1}$, providing a mean annual daily flow of $46.5 \times 10^3 \text{ m}^3 \text{ day}^{-1}$. The long-term mean flows are sufficient to displace the contents of Little Otter Lake, on the average, once every 30 days; the waters of Otter Lake are replaced once every 33 months. During the low-flow summer period, 16-20 weeks are required to displace Little Otter Lake (neglecting the effects of withdrawal). Hydrologists of the Ministry of the Environment pointed out that although sufficient inflow to displace the contents of the lake exists, natural flow patterns and thermal effects may prevent efficient flushing during the summer period and algal-growth stimulating nutrients may be re-dissolved from the bottom sediments. The outflow from Little Otter Lake which is regulated by personnel of the Ministry of Natural Resources, forms the headwaters of the Boyne River and flows to Georgian Bay of Lake Huron via Oastler Lake. Various morphometric and hydrologic data for Otter and Little Otter Lakes are provided in Table 1.

The shoreline of Little Otter Lake is developed for summer recreational activities, having seventeen cottages and twenty commercial units. Rockwell International, formerly the Canadian Motor Lamp Company Limited - (a subsidiary of North American Rockwell) which manufactures parts for the automobile industry, is located near the outlet of the lake (see Figure 1).

Table 1: Morphometric and hydrologic data for Little Otter and Otter Lakes, District of Parry Sound, Ontario.

Parameter	Little Otter Lake	Otter Lake
Area, A_o (ha)	66.5	492
Land drainage area, A_d (ha)	1,062	3,393
Maximum depth, Z (m)	8.0	16.0
Mean Depth, $\bar{Z}$ (m)	2.7	11.0
Lake volume, V (10^6 m^3)	1.85	54.71
Length of shoreline, L (m)	1,195	3,737
Average inflow from Otter Lake narrows ($\text{m}^3 \text{ day}^{-1}$)	35.2×10^3	-
Average land drainage and tributary inflow ($\text{m}^3 \text{ day}^{-1}$)	11.3×10^3	-
Average turnover time (years)	0.10	33

This industry uses approximately $1.89 \times 10^3 \text{ m}^3 \text{ day}^{-1}$ of water from the lake and returns directly $1.81 \times 10^3 \text{ m}^3 \text{ day}^{-1}$ of cooling water to the lake. The treated portion of the effluent ($0.07 \times 10^3 \text{ m}^3 \text{ day}^{-1}$) is conveyed to retention lagoons on the property. Discharge temperatures were slightly higher than background lake water conditions. For example, the temperatures of the industrial effluent as measured at a culvert near its entry to Little Otter Lake average 5.5°C higher than surface water temperatures at Station 3 (see Figure 1), with a range in ΔT of $3.5 - 8.0^\circ \text{C}$. However temperature differences between Station 1 (downstream of the Rockwell International discharge) and Station 3 were barely detectable. The average ΔT was less than 0.5°C with a range of 2.0°C to -0.6°C (based on 16 recordings). During July and August of 1971 when approximately 265 kilograms of phosphorus were discharged in the cooling water stream to the lake, total phosphorus concentrations as high as $3,900 \mu\text{g l}^{-1}$ (July 31, 1971) were measured in the effluent.

The water chemistry of Little Otter Lake is typical of lakes in Northern Ontario where outcrops of Precambrian rocks dominate the basin. These lakes are typically dilute in total chemical concentration and react in the slightly acid to neutral pH range. Some background inorganic chemistry for Little Otter Lake as well as for Lakes Otter, Superior and Huron are presented in Table 2. Ryder (1972), in reviewing the water chemistry of North American oligotrophic lakes, rates Lake Superior as the classical oligotrophic lake type. The conductivity (a measure of the ionic strength) of Little Otter Lake is approximately one-half the value cited for Lake Superior, although transparency in Little Otter Lake is significantly lower than in Lakes Superior or Huron.

METHODS

Field methods: pre-phosphorus reduction

Field efforts in 1971 were minimal as personnel of the Biology Section responded more to confirming the presence of a phytoplanktonic blue-green algal bloom. At the time, little thought was given to evaluating scientifically the effects on water quality of reducing the phosphorus supply to a lake system. As a consequence, the 1971 data consisted of only four mid-lake Secchi disc readings, eight open-water total phosphorus samples and four chlorophyll *a* collections taken at three mid-lake locations. Additionally, nine phytoplankton samples were secured. In most cases, these samples were collected by Ministry staff; however, three of the

Table 2: Background water chemistry for Little Otter and Otter Lakes and comparative data for Lakes Superior and Huron.

Lake	Conductivity ($\mu\text{mhos cm}^{-1}$) at 25 C	pH	H ₂ CO ₃ (mg l ⁻¹)	SO ₄ (mg l ⁻¹)	Cl (mg l ⁻¹)	Ca (mg l ⁻¹)	Secchi disc (m)
Little Otter	50	7.1	15	12	1	6	4
Otter	50	7.1	15	12	1	7	5
Superior*	90	7.4	28	3.2	1	12.4	10
Huron*	192	8.1	50	9.7		22.6	9

* See Conroy (1971) and Ryder (1972)

nine phytoplankton samples were submitted to the Biology Section's laboratories in Toronto by concerned cottagers.

Field methods: post-phosphorus reduction

With the potential value of assessing the effects of phosphorus removal to a lake clearly apparent, a more detailed effort was initiated during the ice-free season of 1972 to confirm whether Little Otter Lake would return to a "normal" condition through comparisons with the minimum 1971 data base and with information collected from the main-lake portion of upstream Otter Lake (see Figure 1). At approximate weekly intervals between May 17 and October 12, 1972, visits were made to three stations in Little Otter Lake and one location in Otter Lake. Water clarity at each site was measured using a Secchi disc (30cm) and dissolved oxygen and temperature profiles were determined using a YSI combination dissolved oxygen-telethermometer unit. Samples for total phosphorus, iron, chlorophyll a and phytoplankton were secured as composites through the euphotic zone (the zone of significant light penetration, calculated as twice the Secchi disc depth) or to 1m above bottom. This was accomplished by lowering and raising a 1000 ml bottle fitted with a restricted inlet through the column at a rate allowing complete filling as the bottle was retrieved to the surface. Additionally, samples for total phosphorus and iron were collected from 1m above bottom using a Van Dorn water sampler. Commencing June 14, analyses of nitrogen (total Kjeldahl, nitrate and free ammonia) were included as part of the routine chemical monitoring programme. The chlorophyll samples were treated with 1 ml of a 2% suspension of magnesium carbonate while the algal samples were preserved with 10 ml of Lugol's iodine solution. All samples were kept cool during transit to Toronto.

In May of 1972, bottom sediments were collected using a 539 cm² Eckman dredge at fifteen stations in Little Otter Lake and three locations in Otter Lake. Sub-samples were dispensed into polyethelene bags and forwarded to Toronto for analyses.

Laboratory methods

Chemical determinations performed on each water sample included total phosphorus (as $\mu\text{g l}^{-1}$ P), total Kjeldahl, nitrate and free ammonia nitrogen (as mg l^{-1} N) and iron (as mg l^{-1} Fe). Analyses on sediment samples

included total phosphorus, total nitrogen (as mg g^{-1} dry weight) and percent loss on ignition. All analyses were standard techniques utilized by the Chemistry Sections of the Ministry. Chlorophyll a determinations were completed following the methods of Brydges (1971).

The algal samples were concentrated by allowing the cells to settle for 72-96 hours, followed by syphoning the overlying liquid. Subsequently, the cells were re-suspended and a 1 ml aliquot was pipetted into a Sedgwick Rafter counting cell. Most of the algal forms were identified to genus at a magnification of 220X. Where accurate identifications were impossible wet mounts were prepared and examined at higher magnifications. Numerical results were recorded as areal standard units (a.s.u.) ml^{-1} . One areal standard unit is equal to an area of 400 square microns (Whipple 1914). The areal value was employed because of its usefulness in measuring standing stocks of algae and because it is extremely useful when relating algal levels to water quality problems. Depending upon the density of cells in the concentrate, strips or fields were counted. To render results statistically accurate, between 150 and 200 organisms ml^{-1} were identified and measured.

Because of the "treat-if-necessary" raison d'être of the programme, special arrangements were made with laboratory staff to ensure that priorities be given to the processing of all samples collected. Usually analytical results were available within 24-36 hours and communicated to personnel involved in the study. At the onset of the programme, it was agreed that chemical treatment (i.e. phosphorus inactivation) of Little Otter Lake would be considered when total phytoplankton populations approached 700-900 a.s.u. ml^{-1} with blue-green bloom-forming species accounting for 30-50% of the total stock and/or chlorophyll a levels exceeding $6-8 \mu\text{g l}^{-1}$ on a "lake-wide" basis.

RESULTS AND DISCUSSION

As indicated earlier, the potential value of assessing the effects of phosphorus removal to a lake system was not clearly apparent until the fall and winter of 1971-1972. The following outline has been designed to confirm the role of phosphorus in promoting algal blooms when added to nutrient-poor Precambrian Shield waters by comparing "before" and "after" phosphorus removal conditions in Little Otter Lake and substantiating these findings through comparisons with upstream Otter Lake.

Pre-phosphorus reduction conditions: Little Otter Lake

The 1971 data for Little Otter Lake have been summarized and are presented in Table 3. Secchi disc visibilities in August and September ranged between 0.1 and 1.0 m. Total phosphorus concentrations near the outlet of the lake were as high as $110 \mu\text{g l}^{-1}$ and exceeded $40 \mu\text{g l}^{-1}$ throughout most of the lake during the period of active discharge, producing high levels of chlorophyll a ($30\text{--}46 \mu\text{g l}^{-1}$) and excessive standing stocks of phytoplankton (approximately 20,000 a.s.u. ml^{-1}). The flora was virtually monospecific in nature with Anabaena limnetica G.M. Smith - a notorious water-bloom forming species dominating.

Post-phosphorus reduction conditions: Little Otter Lake

During the ice-free period of 1972, water quality improvements in Little Otter Lake included increases in Secchi disc transparencies (i.e. 1.8 - 5.2 m) and reductions in total phosphorus (i.e. 6 - $31 \mu\text{g l}^{-1}$) and chlorophyll a (i.e. $0.7\text{--}4.3 \mu\text{g l}^{-1}$) levels. Additionally, lower phytoplankton densities (i.e. approximately 100 - 1,100 a.s.u. ml^{-1}) dominated by chrysophycean and bacillariophycean species were clearly evident (see Table 3).¹

Water clarity Little Otter and Otter Lakes

Secchi disc data are summarized in Table 4 while the seasonal variations in light penetration for representative "deep-water" stations in Little Otter (Station 3) and Otter (Station 4) Lakes are presented in Figure 2. As indicated, water clarity determined from mean Secchi disc readings increased in order from Station 1 - (Little Otter Lake) through Station 4 (Otter Lake). When considering this progressive increase, it should be recognized that Secchi disc readings - especially at Station 1 - were governed by the shallow nature of the sampling site (i.e. 3.4m) and hence reflect the effects of complete mixing owing to wind and wave action. The lowest 1972 reading (1.8m) occurred at Station 1 on August 9: this recording was significantly higher than those measured (0.1 - 1.0m) in August and September of 1971 during the blue-green algal water bloom (see Figure 2).

¹ The 1973 conditions during the ice-free season of the year were similar to those observed in 1972 i.e. Secchi disc transparencies 2.0 - 5.6m, total phosphorus 10 - $27 \mu\text{g l}^{-1}$ and chlorophyll a $0.8\text{--}3.5 \mu\text{g l}^{-1}$ (see Keller and Conroy 1974).

Table 4: Mean and extreme values for Secchi disc (m), total phosphorus ($\mu\text{g l}^{-1}$ as P), total Kjeldahl Nitrogen (mg l^{-1} as N), iron (mg l^{-1} as Fe) and chlorophyll a ($\mu\text{g l}^{-1}$) in the euphotic zone and at 1m above bottom at three locations in Little Otter Lake and one station in Otter Lake. Collections were made on 21 dates between May 17 and October 12, 1972.

Station	Secchi disc		Total Phosphorus		Total Kjeldahl Nitrogen		Free Ammonia Nitrogen		Nitrate Nitrogen		Iron		Chlorophyll a	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Little Otter Lake														
1e ¹	2.5	1.8-3.4	14	8-29	.35	.25-.55	.03	.01-.07	.01	.01-.03	.08	.05-.21	2.4	0.7-4.3
b ²			15	8-22	.33	.23-.60	.05	.01-.38	.01	.01-.02	.09	.05-.25		
2e	3.6	2.9-4.0	13	8-26	.29	.22-.35	.03	.01-.13	.01	.01-.01	.07	.04-.11	2.6	0.9-4.2
b			16	8-31	.32	.24-.56	.03	.01-.13	.01	.01-.02	.08	.05-.12		
3e	3.8	2.6-5.2	13	6-25	.27	.21-.33	.02	.01-.09	.01	.01-.01	.07	.04-.14	2.6	0.7-4.6
b			13	6-25	.29	.22-.42	.02	.01-.08	.01	.01-.01	.08	.04-.25		
Otter Lake														
4e	4.6	3.7-5.8	12	5-37	.27	.20-.53	.04	.01-.16	.01	.01-.03	.07	.02-.50	1.8	0.5-3.7
b			10	5-16	.23	.20-.29	.04	.01-.16	.11	.07-.16	.07	.04-.11		

1 = euphotic zone sample

2 = sample collected at 1m above bottom

Table 3: Summary of Secchi disc, total phosphorus, chlorophyll a and phytoplankton data for Little Otter Lake, 1971 and 1972.

	1971			1972		
	Range	Mean	Number of Analysis	Range	Mean	Number of Analysis
Secchi disc (m)	0.1 - 2.3	1.0	4	1.8 - 5.2	3.3	57
Total Phosphorus ($\mu\text{g l}^{-1}$ as P)	12 - 110	57.2	8	6 - 31	14.1	113
Chlorophyll <u>a</u> ($\mu\text{g l}^{-1}$)	12 - 46	31.2	4	0.7 - 4.3	2.5	57
Phytoplankton						
a) Quantity (a.s.u. ml^{-1})	667 - 19,387	5,175	9	84 - 1,114	399	63
b) Species	<u>Anabaena limnetica</u>			<u>Dinobryon bavaricum</u> <u>D. sertularia</u> <u>D. sociale</u> <u>Chrysosphaerella longispina</u>		

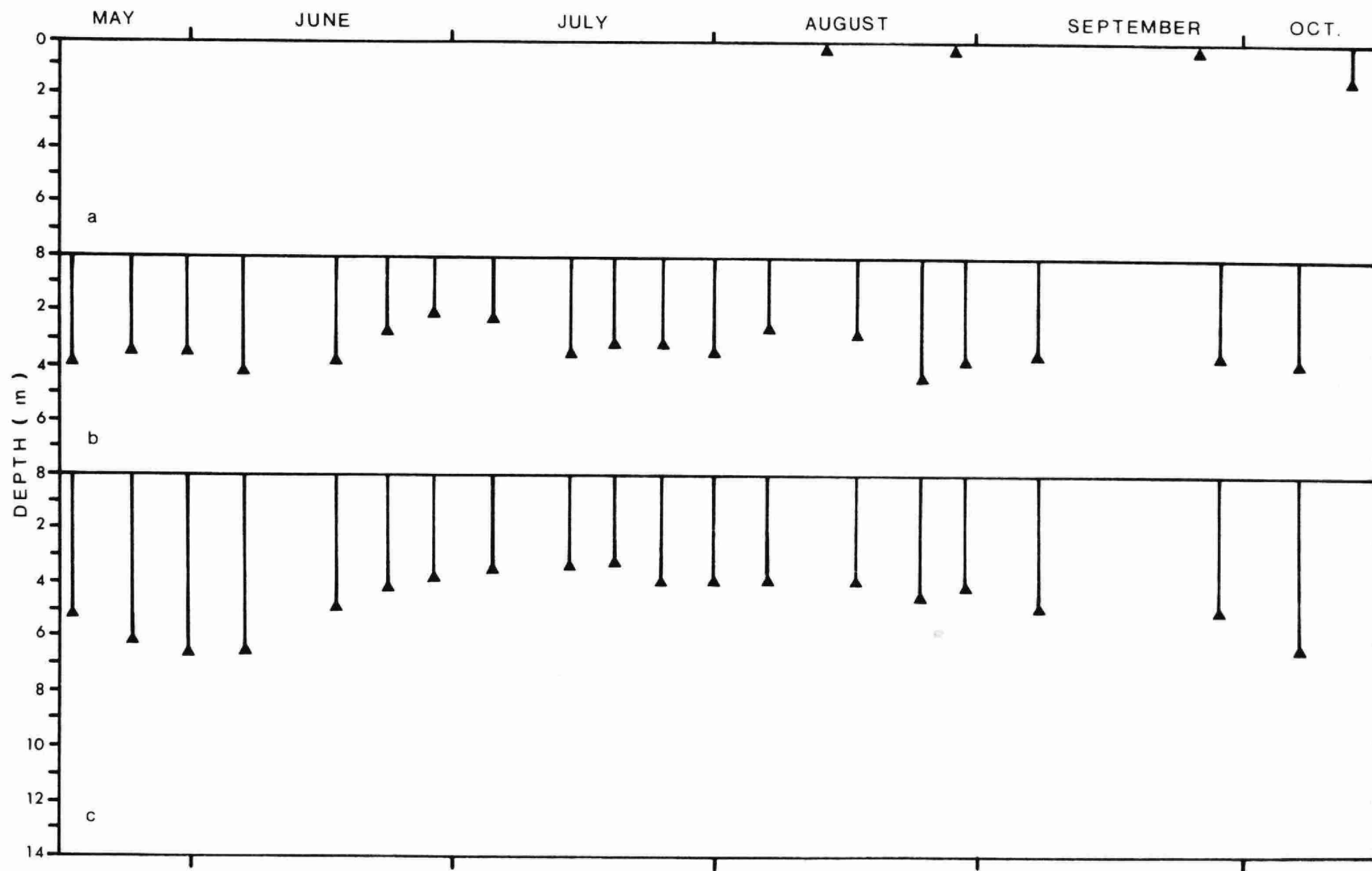


Figure 2: Secchi disc readings (m) on four dates in Little Otter Lake in 1971 (a), as well as seasonal variations in light penetrations at Station 3 in Little Otter Lake and at Station 4 in Otter Lake (b and c, respectively) in 1972.

Temperature and dissolved oxygen conditions: Little Otter and Otter Lakes

In general, Little Otter Lake was near-homothermous during the entire 1972 sampling season, with surface water temperatures as high as 26.0 °C at Station 1 (July 12). A well-defined thermocline (comparable to a second order lake of Hutchinson 1957) characterized Otter Lake during the sampling period. Temperatures in Little Otter Lake were always higher than those recorded from similar strata of Otter Lake.

Oxygen distributions were orthograde for both lakes although a slight indication of a positive heterograde oxygen distribution or metalimnetic maximum was noted in Otter Lake.

Nutrient conditions: Little Otter and Otter Lakes

Water

The seasonal patterns for total phosphorus and Kjeldahl nitrogen in the euphotic zone and at 1m above bottom for representative deep-water stations in the two lakes are presented in Figure 3. For comparative purposes, 1971 phosphorus data for Little Otter Lake are illustrated. Also, information on total phosphorus, total Kjeldahl, free ammonia and nitrate nitrogen and iron at each station monitored in 1972 is summarized in Table 4. As indicated, only minor differences were noted in phosphorus concentrations between the surface and bottom waters of Little Otter and Otter Lakes, although concentrations at Station 1 of Little Otter Lake were usually somewhat higher than those recorded elsewhere in the system.

In general, periodic troublesome levels of algae materialize in soft-water Precambrian lakes when mean total phosphorus concentrations during the ice-free period of the year exceed 20 $\mu\text{g l}^{-1}$. As depicted in Table 4, mean euphotic zone total phosphorus values for 1972 at the four locations were below this critical level, reflecting the unproductive nature of the lakes. In contrast, during the late summer and early fall of 1971 concentrations near the outlet of Little Otter Lake were as high as 110 $\mu\text{g l}^{-1}$ and exceeded 40 $\mu\text{g l}^{-1}$ throughout most of the lake - indicating the impact of the polyphosphate de-scaling agent.

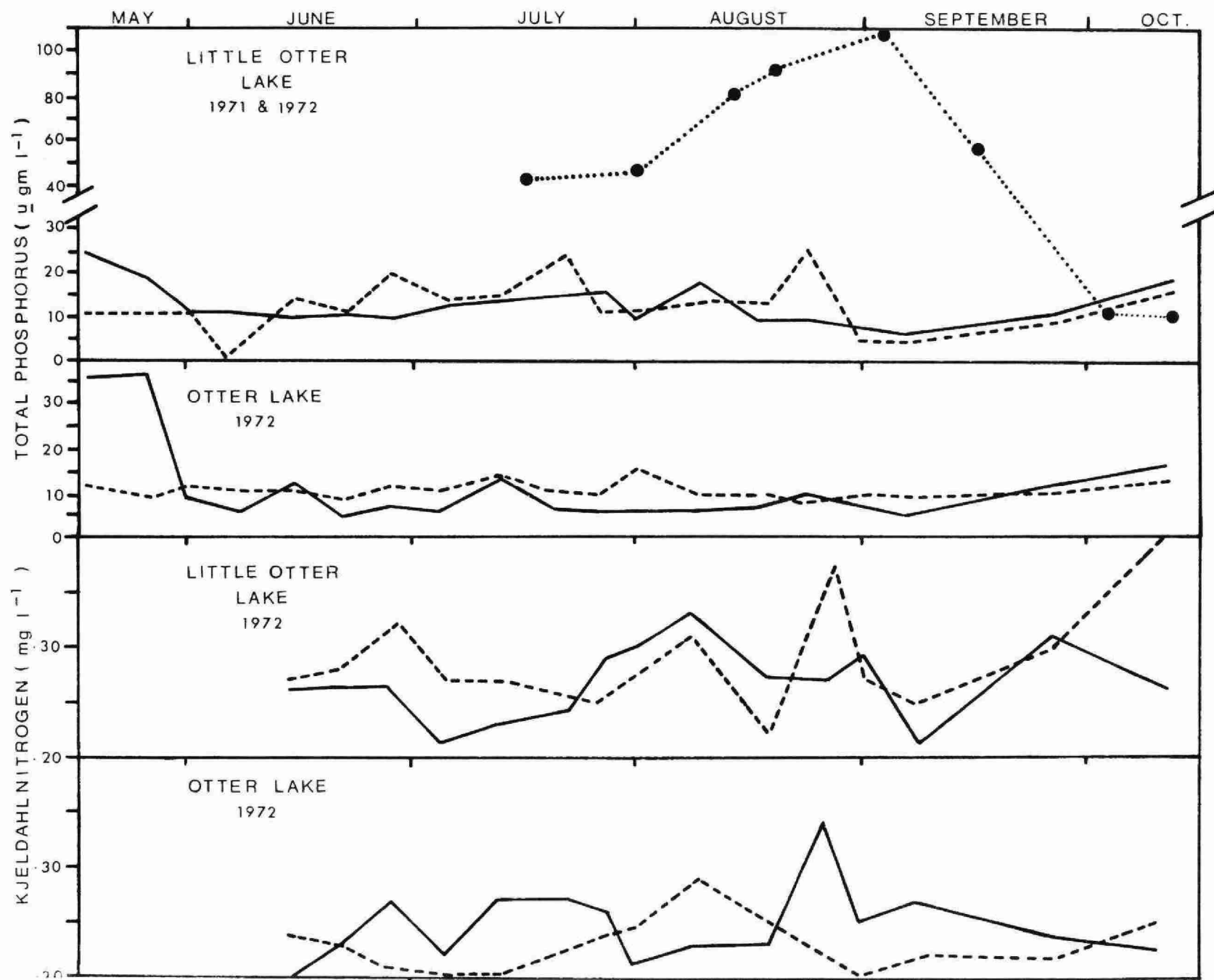


Figure 3: The seasonal patterns for total phosphorus and Kjeldahl nitrogen in the euphotic zones (solid lines) and at 1m above bottom (broken lines) of Little Otter and Otter Lakes, 1972. Total phosphorus data on eight dates in 1971 in Little Otter Lake are presented as closed circles in upper plate.

Although total Kjeldahl nitrogen values were slightly higher in Little Otter than in Otter Lake, clearly defined seasonal and depth patterns were not evident (Figure 3). Euphotic zone and bottom water levels averaged 0.30 and 0.31 mg l^{-1} , respectively, for the former lake and 0.27 and 0.23 mg l^{-1} , respectively for the latter lake. Nitrate nitrogen depletions characterized the illuminated waters of both lakes; deep-water accumulations were noted only in Otter Lake (Table 4).

Sediments

Since phosphorus was the only significant input to Little Otter Lake, the ratio of mean total phosphorus to mean total nitrogen in the bottom sediments was considered to be a meaningful indication of the relative increase of phosphorus in the bottom sediments. A sketch of the lakes indicating the sediment sampling stations, and the mean ratio of phosphorus to nitrogen for various arbitrarily defined areas is presented in Figure 4. Samples having less than 10% loss on ignition, indicating low organic content were excluded from the calculations. The ratio of mean total phosphorus to mean total nitrogen in the area adjacent to the industrial discharge was twice as high as that found in Otter Lake (P:N of 0.59 and 0.26 , respectively), indicating that some of the polyphosphate de-scaler had been incorporated into the bottom sediments. Ratios for other sections of Little Otter Lake varied from 0.17 to 0.23 with the lowest ratios occurring in the area proximal to the inflowing narrows. An examination of the total phosphorus concentrations in the water near the inlet and outlet (see Table 3) shows that higher levels were recorded in the latter than in the former waters. It is possible that the sediments near the Rockwell International discharge are providing a continuous source of phosphorus to the overlying waters - most likely from wind-induced action - and water-borne phosphorus concentrations at the outlet will remain elevated until sediment-phosphorus reductions occur.

Chlorophyll a and phytoplankton stocks: Otter and Little Otter Lakes

An indication of the seasonal patterns in chlorophyll a concentrations at Stations 3 and 4 in Little Otter and Otter Lakes is presented in Figure 5, while the maximum, minimum and mean values for each sampling site are summarized in Table 4. Also, the few 1971 data available for Little Otter Lake are presented in Figure 5. As indicated, the 1972 plant pigment concentrations for both lakes were very low. For example,

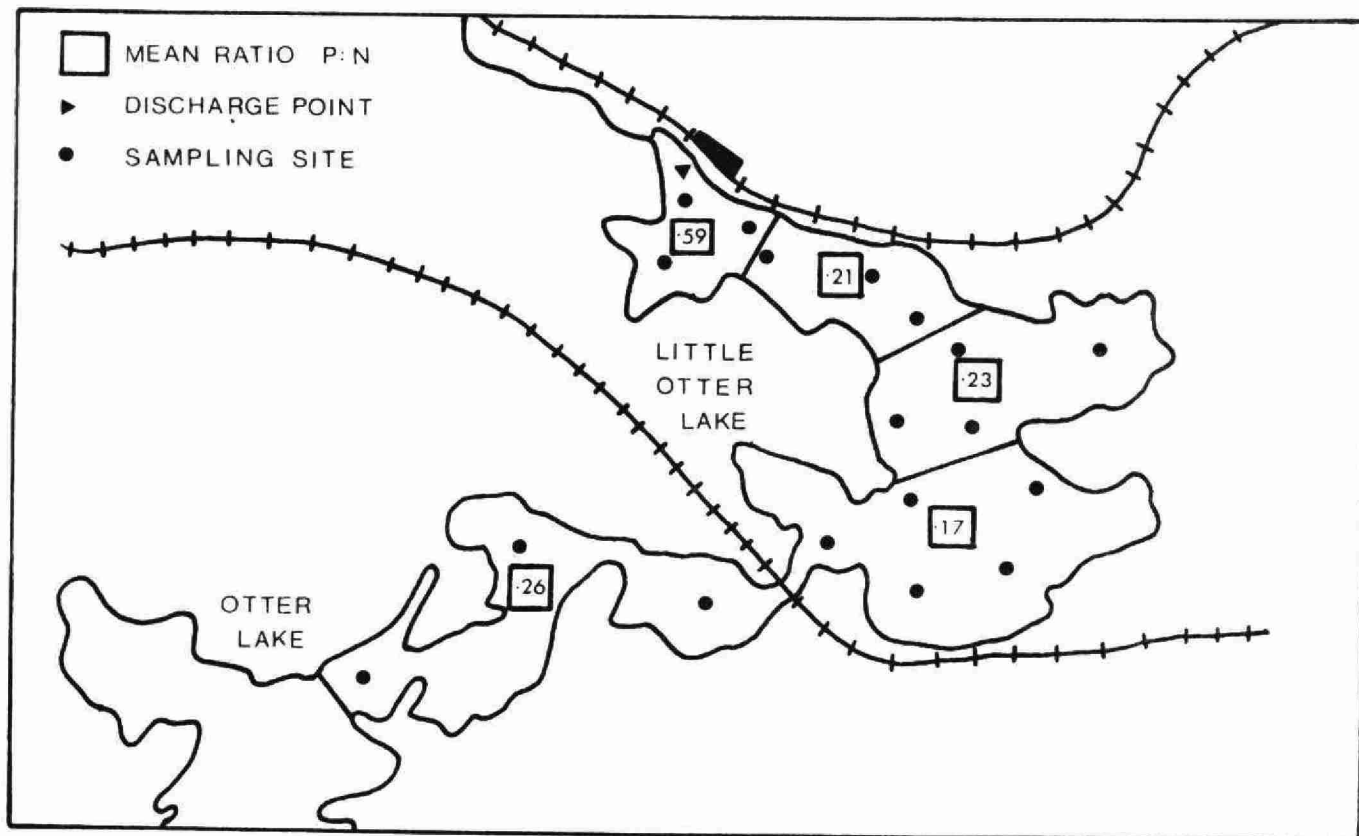


Figure 4: Mean weight ratios of total phosphorus to total nitrogen in sediments in four arbitrarily defined areas in Little Otter and Otter Lakes, May 1972.

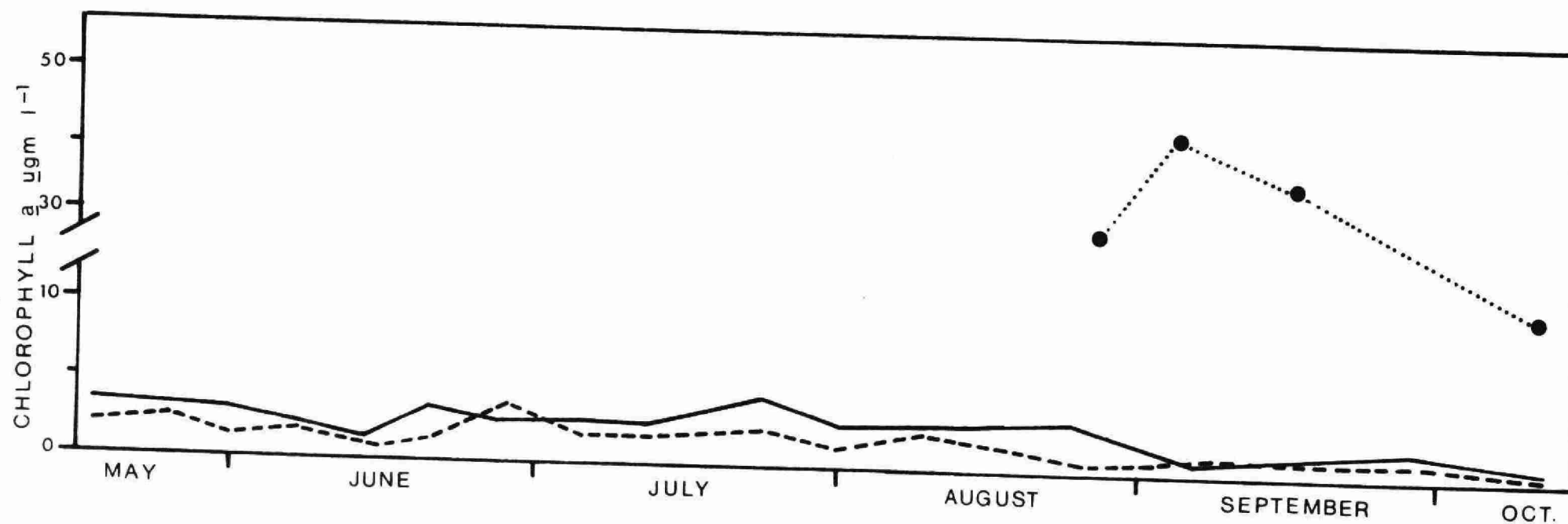


Figure 5: Seasonal trends in chlorophyll *a* ($\mu\text{g l}^{-1}$) in the euphotic zones of Station 3 in Little Otter Lake (solid line) and Station 4 in Otter Lake (broken line), 1972. Chlorophyll *a* data on four dates in 1971 in Little Otter Lake are indicated as closed circles.

a maximum chlorophyll value of $4.3 \mu\text{g l}^{-1}$ at Station 1 was recorded on June 16; usually concentrations in the lake rarely exceeded $3.0 \mu\text{g l}^{-1}$. In contrast, during August and September of 1971, levels as high as $46 \mu\text{g l}^{-1}$ developed in the affected lake and reduced recreational activities such as swimming, boating and waterskiing and diminished the aesthetic quality of the lake. Significantly, since excessive algal growths did not develop during the summer of 1972, water-oriented recreational pursuits were not diminished.

The seasonal pattern in phytoplankton development (in a.s.u. ml^{-1}) and successional changes for the major taxonomic classifications (expressed as percent composition) are presented in Figure 6. A bimodal pattern in phytoplankton development occurred in Little Otter Lake; the first materialized during June while the second occurred during the latter weeks of July and the first part of August. The June pulse did not develop in Otter Lake although the mid-summer maximum was of lengthy duration.

Phytoplankton stocks averaging 400 and 405 a.s.u. ml^{-1} for Little Otter and Otter Lakes, respectively are considered to be low in magnitude. Table 5 provides, for comparative purposes, a breakdown of phytoplankton conditions for several lakes in Ontario. The data are based on collections approximating the same ice-free period when samplings were obtained for Little Otter and Otter Lakes (although years are different). As indicated, standing stocks of phytoplankton in the study area are similar to those of nearby Lakes Joseph, Rosseau and Georgian Bay - three oligotrophic bodies of water - and are significantly lower than those recorded for the Union Water Treatment Plant located on the northern shoreline of the Western Basin of Lake Erie, Dows Lake near Ottawa, Riley Lake and Gravenhurst Bay - four extremely enriched bodies of water.

In general the community structure for Little Otter Lake differed somewhat from that of Otter Lake. For example, the dominant plankters in the former included three species of Dinobryon (D. bavaricum Imhoff, D. sertularia Ehr. and D. sociale Ehr.), Tabellaria fenestrata (Lyngb.) Kütz. and Chrysphaerella longispina Lauterborn whereas the most important forms in Otter Lake were Asterionella formosa Hass., Merismopedia tenuissima Lemmerman, three species of Aphanothece (A. nidulans P. Richter, A. gelatinosa (Henn.) Lemmerman and A. clathrata G.S. West) and Chroococcus limneticus Lemmerman. Although A. formosa appears to be ubiquitous and occupies a broad ecological niche (see Stoermer and Yang 1970, Veal and Michalski 1971 and Michalski et al. 1973), the remaining aforementioned species

Figure 6: Phytoplankton stocks and composition in the euphotic zone at Station 3 in Little Otter Lake (b) and at Station 4 in Otter Lake (c) during the ice-free period of 1972. Additionally, data on nine dates in 1971 in Little Otter Lake (a) are presented for comparative purposes (note quantitative difference in a.s.u. values between 1971 and 1972).

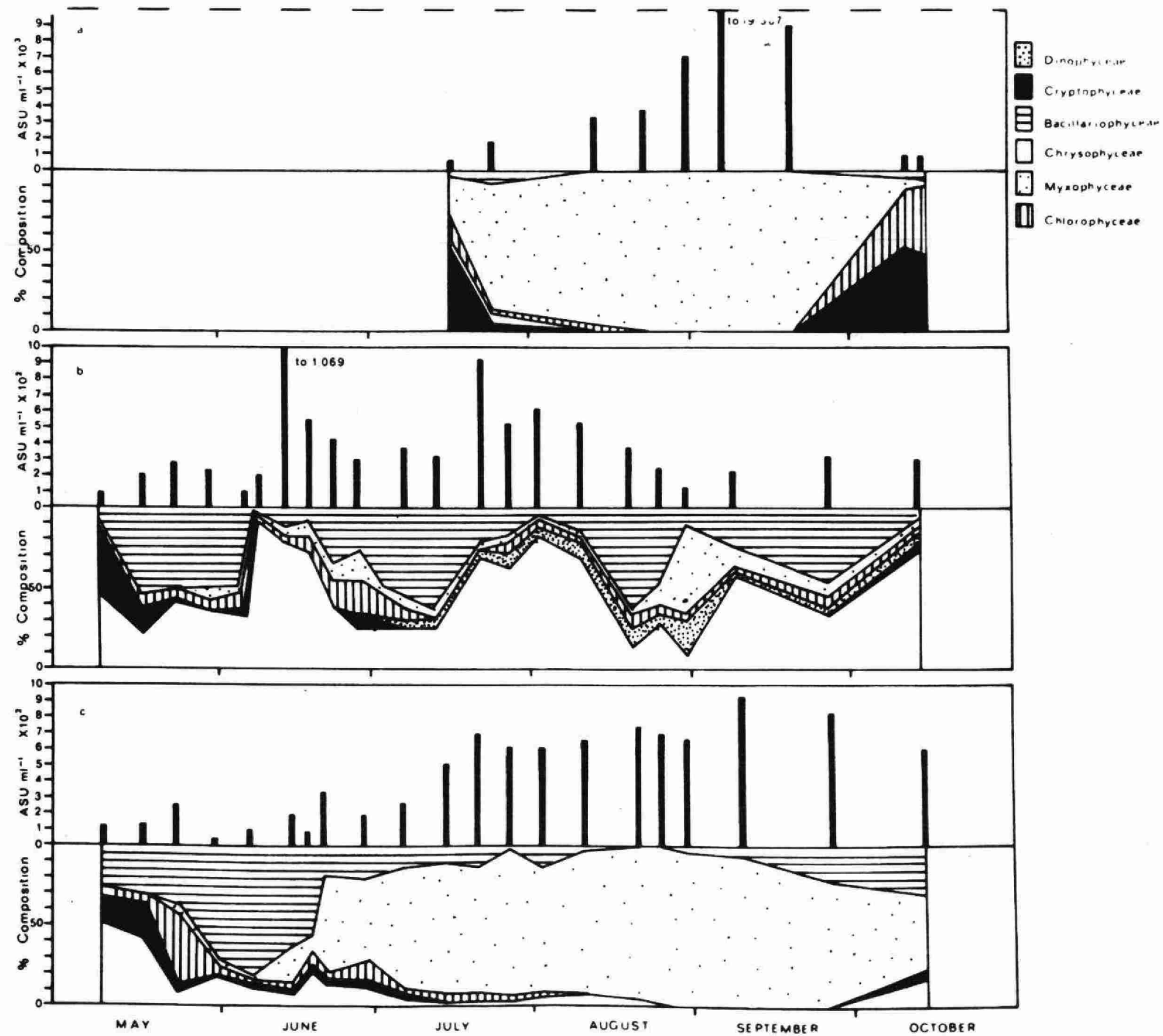


Table 5: Summary of phytoplanktonic data collected from three locations in Little Otter Lake and one station in Otter Lake during the summer of 1972 and from various sources in the province. 1971 data for Little Otter Lake are presented for comparison. All collections were made during the ice-free period of the year indicated. Results are expressed as areal standard units ml^{-1} .

Municipality	Source and Year	Number of Samples	Areal Standard Units ml^{-1}		Trophic Status
			Range	Mean	
-	Lake Joseph, 1969	21	31- 1,153	402	Oligotrophic
-	Lake Rosseau, 1969	22	54- 1,880	479	Oligotrophic
Collingwood	Georgian Bay, 1968	207	7- 708	226	Oligotrophic
Kingsville Union	Lake Erie, Western Basin, 1969	26	1,022- 7,147	3,190	Eutrophic
Ottawa	Dows Lake, 1969	20	455-13,651	5,581	Eutrophic
-	Riley Lake, 1969	72	141- 5,056	1,912	Eutrophic
Gravenhurst	Gravenhurst Bay, 1969	25	134- 6,402	2,686	Eutrophic
-	Little Otter Lake, 1971	9	667-19,387	5,175	Eutrophic
-	Little Otter Lake - Station 1, 1972	21	101- 1,114	404	Oligotrophic
-	Little Otter Lake - Station 2, 1972	21	84- 1,083	412	Oligotrophic
-	Little Otter Lake - Station 3, 1972	21	103- 1,069	382	Oligotrophic
-	Otter Lake - Station 4, 1972	21	33- 910	405	Oligotrophic

are normally found in Precambrian Shield lakes having low nutrient conditions (see Michalski et al. 1973). The fact that chroococcolean blue-green algae did not comprise a large proportion of the total mid-summer biomass in Little Otter Lake is somewhat surprising as most species of this taxonomic grouping are common to the flora of unenriched shield lakes (see Michalski and Robinson 1969, Michalski 1971 and Michalski et al. 1973). Reasons for this as well as for the preponderance of Chrysophceae in Little Otter Lake are not clear; however, major differences in the thermal regimes and morphometric features of the lake relative to the deep, thermally stratified waters of Otter Lake may influence associated species compositions. In 1971, the late summer and early fall phytoplankton levels for Little Otter Lake were dominated almost exclusively by high numbers ($19,338 \text{ a.s.u. ml}^{-1}$) of Anabaena limnetica - a notorious "water-bloom" forming species. Only rare occurrences of this alga were encountered in 1972. It is suggested that the aforementioned changes in standing stocks and species composition in Little Otter Lake resulted from the reduced phosphate loading effected by Rockwell International. Conditions which could have initiated chemical treatment for phosphorus precipitation (i.e. phytoplankton stocks ranging between 700-900 a.s.u. ml^{-1} with blue-green forming species accounting for 30-50% of the total biomass and/or chlorophyll levels exceeding $6-8 \mu\text{g l}^{-1}$) did not materialize during the summer of 1972.

Water management implications

Personnel involved in water management programmes in Ontario are placing emphasis on eliminating artificial point-source discharges of phosphorus from conventional sewage treatment plants to reverse conditions of accelerated enrichment in lakes. Recently, Vollenweider (1968) proposed a relatively simple measure of eutrophication using an empirical phosphorus loading - mean depth relationship. This model (see Figure 7) has been employed as a guide in defining the degree of eutrophy of a lake and in establishing "permissible" and "dangerous" phosphorus loading levels (see Schindler and Nighswander 1970, Schindler et al. 1971, Patalas 1972 and Ahl 1972). As pointed out in Anon. (1969), "The upward slope of the two lines enclosing the range of mesotrophy is in good agreement with the accepted fact that the deeper the lake and the greater its volume, the greater its capacity to absorb a given nutrient load."

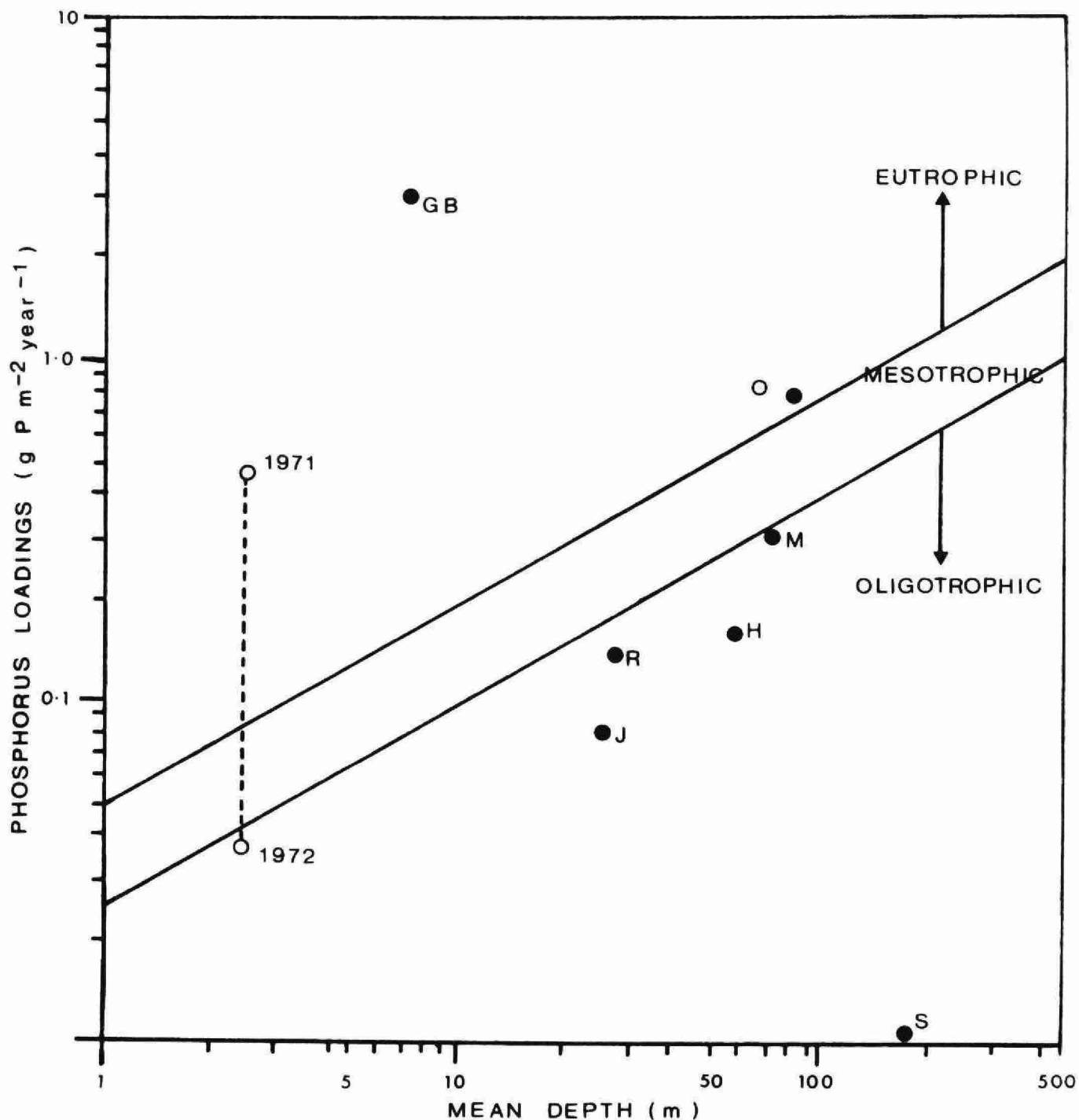


Figure 7: State of eutrophication for a number of inland Ontario Lakes and Laurentian Great Lakes. Lakes above the upper diagonals are eutrophic in status while lakes below the lower diagonal are oligotrophic. Lakes between the diagonals are mesotrophic. Total phosphorus loadings to Gravenhurst Bay (GB, 1969), Lake Rosseau (R, 1969) and Lake Joseph (J, 1969) are from Michalski et al. (1973) while inputs to Lake Superior (S), Huron (H), Michigan (M) and Ontario (O) are reproduced from Patalas (1972).

Total phosphorus loadings to Little Otter Lake from the upstream lake, immediate land drainage, cottages and resorts and industrial discharges were calculated and are presented in Table 6. Our calculation for soil inputs of $0.019 \text{ g P m}^{-2} \text{ year}^{-1}$ is in good agreement with that reported by Patalas (1972) for Lake Superior ($0.015 \text{ g P m}^{-2} \text{ year}^{-1}$), but is somewhat lower than that presented by the same author for Lake Huron ($0.044 \text{ g P m}^{-2} \text{ year}^{-1}$). It is suggested that the Little Otter Lake drainage basin reflects an impoverished phosphorus source and predictively should produce lower charging rates than the overall Lake Huron basin where more recent Paleozoic limestone predominates. Because Little Otter Lake was essentially a closed system during the two month period of active discharge, our phosphorus loading rates were calculated on the basis of inputs entering the lake during the discharge months only (see Table 6).

Loadings to Little Otter Lake as well as to a number of other lakes are presented in Figure 7. The open circle for Little Otter Lake refers to the 1971 calculation ($0.436 \text{ g P m}^{-2} \text{ year}^{-1}$) which exceeds the acknowledged dangerous level. However, once the use of the polyphosphate chemical was discontinued, the "improved" 1972 loading rate ($0.036 \text{ g P m}^{-2} \text{ year}^{-1}$) was such that the relative trophic status for Little Otter Lake was reduced from a decidedly eutrophic to an oligotrophic condition. Significantly, the observed biological and chemical changes from a highly enriched lake (i.e. Little Otter Lake in 1971) to a relatively unproductive system (i.e. Little Otter Lake in 1972) corresponded completely with changes which would be expected on the basis of Figure 7. As indicated earlier, sediment phosphorus to nitrogen ratios as well as lake-water phosphorus concentrations in the vicinity of the Rockwell International discharge were somewhat higher than elsewhere in the study area; incorporation of phosphorus from bottom sediments following periods of intense wind and wave action may act to prolong the complete recovery of Little Otter Lake to its former condition.

In past years many approaches to determine whether phosphorus removal will effectively control algal growths have been taken from the point of view of adding chemicals to systems (i.e. additions to laboratory flasks and in situ plastic tube and lake-scale experiments). With the exception of Edmondson (1971), very little effort has gone into assessments of "taking away" an element critical to plant growth. The Little Otter Lake situation can, with appropriate qualifications be classified as a lake-scale phosphorus removal study. In light of the findings which indicate that improved water quality resulted following phosphorus

Table 6: Phosphorus loading rates (i.e. kg year^{-1} and $\text{g P m}^{-2} \text{ year}^{-1}$) from land drainage, main-lake above, cottages and resorts and industrial discharges to Little Otter Lake, 1971. Calculations are based on loadings to the lake during the period of active discharge (i.e. during the summer months when the lake was essentially a closed system)

	kg year^{-1}	$\text{g P m}^{-2} \text{ year}^{-1}$
Land drainage	2.46 3.52 *	0.003
Main-lake above	11.16 $\emptyset$	0.016
Industrial discharge	265.50	0.400
Cottage and resort inputs	11.40 ^x	0.017
Total	291.58 290.52	0.436

* Pro-rated on the basis of phosphorus leachate from a 1,062 ha drainage basin of concentration $15 \mu\text{g l}^{-1}$ as P.

$\emptyset$ Calculated using an average flow of $12.49 \times 10^3 \text{ m}^3 \text{ day}^{-1}$ measured at the Otter - Little Otter Lake narrows during July and August of 1971 and a concentration of $15 \mu\text{g l}^{-1}$ as P.

^x Contributions calculated after Michalski et al. 1973

reduction, one must view the Province's phosphorus removal programme with a certain amount of optimism. Reflectively, however, some caution must be exercised in predicting benefits that will occur for all situations based on the Little Otter Lake results, as the situation was not typical of a continuously affected lake nor was it influenced by a mixture of nutrients such as characterizes a treated municipal discharge.

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APPENDIX 'A'

Chronology of water quality investigations of Little Otter Lake

Date	Nature of investigation	Reporting agency
October, 1966	Biological survey - bottom fauna - chromium conditions	Ontario Water Resources Commission - Biology Branch
August 24-26 1970	Recreational Lakes Programme - bacteriology - chemistry - biology	Ontario Water Resources Commission - Sanitary Engineering Division
August 16, 1971	Spot survey - chemistry - phytoplankton	Ontario Water Resources Commission - Industrial Wastes Division
August 18-19, 1971	Lake survey	Ministry of Natural Resources
September 5, 1971	Spot survey - chemistry - biology	Ontario Water Resources Commission - Biology Branch
September 22, 1971	Spot survey - phosphorus concentrations	Ontario Water Resources Commission - Industrial Wastes Division
October 12, 1971	Spot survey - chemistry - biology	Ontario Water Resources Commission - Biology Branch
October 21, 1971	Fish survey - heavy metals content	Ministry of Natural Resources
May 9-11, 1971	Biological survey - physical - chemistry - biology	Ministry of the Environment
May 17 - Oct. 12, 1972	Monitoring programme - physical - chemistry - biological	Ministry of the Environment - Biology Section
May - September 1973	"Self-Help" programme - chlorophyll <u>a</u> - Secchi disc	Foley Township Cottagers Association ¹

Appendix 'A' - Cont'd....

Date	Nature of investigation	Reporting agency
August 18, 1973	Spot survey	Ministry of the Environment - Industrial Wastes Branch
August 23, 1973	Biological survey - physical - chemistry - biology	Ministry of the Environment - Biology Section ²

¹ Data available in report by Keller and Conroy, 1974

² Data available in Biology Section's Regional Office files
(Sault Ste Marie).

